HIGH CARBON STEEL SHEET AND PRODUCTION METHOD THEREOF

This application is a divisional application of Application Serial No. 09/961,843 filed September 24, 2001 (now allowed), which is a continuation application of International Application PCT/JP01/00404 filed January 23, 2001.

TECHNICAL FIELD

The present invention relates to a high carbon steel sheet having chemical composition specified by JIS G 4051 (Carbon steels for machine structural use), JIS G 4401 (Carbon tool steels) or JIS G 4802 (Cold-rolled steel strips for springs), and in particular to a high carbon steel sheet having excellent hardenability and toughness, and workability with a high dimensional precision, and a method of producing the same.

BACKGROUND ART

High carbon steel sheets having chemical compositions specified by JIS G 4051, JIS G 4401 or JIS G 4802 have conventionally much often been applied to parts for machine structural use such as washers, chains or the like. Such high carbon steel sheets have accordingly been demanded to have good hardenability, and recently not only the good hardenability after quenching treatment but also low temperature - short time of quenching treatment for cost down and high toughness after quenching treatment for safety during services. In addition, since the high carbon steel sheets have large planar anisotropy of mechanical properties caused by production process such as hot rolling, annealing and cold rolling, it has been difficult to apply the high carbon steel sheets to parts as gears which

are conventionally produced by casting or forging, and demanded to have workability with a high dimensional precision.

Therefore, for improving the hardenability and the toughness of the high carbon steel sheets, and reducing their planar anisotropy of mechanical properties, the following methods have been proposed.

(1) JP-A-5-9588, (the term "JP-A" referred to herein signifies "Unexamined Japanese Patent Publication") (Prior Art 1): hot rolling, cooling down to 20 to 500 °C at a rate of 10 °C/sec or higher, reheating for a short time, and coiling so as to accelerate spheroidization of carbides for improving the hardenability.

(2) JP-A-5-98388 (Prior Art 2): adding Nb and Ti to high carbon steels containing 0.30 to 0.70 % of C so as to form carbonitrides for restraining austenite grain growth and improving the toughness.

(3) "Material and Process", vol.1 (1988), p.1729 (Prior Art 3): hot rolling a high carbon steel containing 0.65 % of C, cold rolling at a reduction rate of 50 %, batch annealing at 650 °C for 24 hr, subjecting to secondary cold rolling at a reduction rate of 65 %, and secondary batch annealing at 680 °C for 24 hr for improving the workability; otherwise adjusting the chemical composition of a high carbon steel containing 0.65 % of C, repeating the rolling and the annealing as above mentioned so as to graphitize cementites for improving the workability and reducing the planar anisotropy of r-value.

(4) JP-A-10-152757 (Prior Art 4): adjusting contents of

C, Si, Mn, P, Cr, Ni, Mo, V, Ti and Al, decreasing S content below 0.002 wt%, so that 6 μm or less is the average length of sulfide based non metallic inclusions narrowly elongated in the rolling direction, and 80 % or more of all the inclusions are the inclusions whose length in the rolling direction is 4 μm or less, whereby the planar anisotropy of toughness and ductility is made small.

(5) JP-A-6-271935 (Prior Art 5): hot rolling, at Ar3 transformation point or higher, a steel whose contents of C, Si, Mn, Cr, Mo, Ni, B and Al were adjusted, cooling at a rate of 30 °C/sec or higher, coiling at 550 to 700 °C, descaling, primarily annealing at 600 to 680 °C, cold rolling at a reduction rate of 40 % or more, secondarily annealing at 600 to 680 °C, and temper rolling so as to reduce the planar shape anisotropy caused by quenching treatment.

However, there are following problems in the above mentioned prior arts.

Prior Art 1: Although reheating for a short time, followed by coiling, a treating time for spheroidizing carbides is very short, and the spheroidization of carbides is insufficient so that the good hardenability might not be probably sometimes provided. Further, for reheating for a short time until coiling after cooling, a rapidly heating apparatus such as an electrically conductive heater is needed, resulting in an increase of production cost.

Prior Art 2: Because of adding expensive Nb and Ti, the

production cost is increased.

Prior Art 3: $\Delta r = (r0 + r90 - 2 \times r45)/4$ is -0.47, which is a parameter of planar anisotropy of r-value (r0, r45, and r90 shows a r-value of the directions of 0° (L), 45° (S) and 90° (C) with respect to the rolling direction respectively). Δmax of r-value being a difference between the maximum value and the minimum value among r0, r45, and r90 is 1.17. Since the Δr and the Δmax of r-value are high, it is difficult to carry out a forming with a high dimensional precision.

Besides, by graphitizing the cementites, the Δr decreases to 0.34 and the Δmax of r-value decreases to 0.85, but the forming could not be carried out with a high dimensional precision. In case graphitizing, since a dissolving speed of graphites into austenite phase is slow, the hardenability is remarkably degraded.

Prior Art 4: The planar anisotropy caused by inclusions is decreased, but the forming could not be always carried out with a high dimensional precision.

Prior Art 5: Poor shaping caused by quenching treatment could be improved, but the forming could not be always carried out with a high dimensional precision.

DISCLOSURE OF THE INVENTION

The present invention has been realized to solve above these problems, and it is an object of the invention to provide a high carbon steel sheet having excellent hardenability and toughness, and workability with a high dimensional precision,

and a method of producing the same.

The present object could be accomplished by a high carbon steel sheet having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, in which the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, more than 50 carbides having a diameter of 1.5 μm or larger exist in 2500 μm^2 of observation field area of electron microscope, and the Δr being a parameter of planar anisotropy of r-value is more than -0.15 to less than 0.15.

The above mentioned high carbon steel sheet can be produced by a method comprising the steps of: hot rolling a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the cold rolled steel sheet at 620 to 680 °C.

The JIS G standards JIS G 4051 (1979), JIS G 4401:2000 and JIS G 4802:1999 and particularly the section of each disclosing the chemical composition, are hereby incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the relationship between maximum diameter Dmax of carbide when 80 % or more is the ratio of number of carbides having diameters ≦ Dmax with respect to all the carbides and hardness after quenching treatment;

Fig. 2 shows the relationship between number of carbides

having a diameter of 1.5 μm or larger which exist in 2500 μm^2 of observation field area of electron microscope and austenite grain size;

Fig. 3 shows the relationship between primary annealing temperature, secondary annealing temperature and Δmax of r-value; and

Fig. 4 shows the another relationship between primary annealing temperature, secondary annealing temperature and Δ max of r-value.

EMBODIMENTS OF THE INVENTION

As to the high carbon steel sheet containing chemical composition specified by JIS G 4051, JIS G 4401 or JIS G4802, we investigated the hardenability, the toughness and the dimensional precision when forming, and found that the existing condition of carbides precipitated in steel was a governing factor over the hardenability and the toughness, while the planar anisotropy of r-value was so over the dimensional precision when forming, and in particular for providing an enough dimensional precision when forming, the planar anisotropy of r-value should be made smaller than that of the prior art. The details will be explained as follows.

(i) Hardenability and toughness

By making a steel having, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, hot rolling at a finishing temperature of 850 °C, coiling at a coiling temperature of 560 °C, pickling, primarily annealing at 640 to

690 °C for 40 hr, cold rolling at a reduction rate of 60 %, and secondarily annealing at 610 to 690 °C for 40 hr, steel sheets were produced. Cutting out samples of 50 x 100 mm from the produced steel sheets, and heating at 820 °C for 10 sec, followed by quenching into oil at around 20 °C, the hardness was measured and carbides were observed by an electron microscope.

The hardness was averaged over 10 measurements by Rockwell C Scale (HRc). If the average HRc is 50 or more, it may be judged that the good hardenability is provided.

The carbides were observed using a scanning electron microscope at 1500 to 5000 magnifications after polishing the cross section in a thickness direction of the steel sheet and etching it with a picral. Further, measurements were made on the size and the number of carbides in an observation field area of 2500 μm^2. The reason for preparing the observing field area of 2500 μm^2 was that if an observing field area was smaller than this, the number of observable carbides was small, and the size and the number of carbides could not be measured precisely.

Fig. 1 shows the relationship between maximum diameter Dmax of carbide when 80 % or more is the ratio of number of carbides having diameters $\leqq$ Dmax with respect to all the carbides and hardness after quenching treatment.

If the ratio of number of carbides having a diameter of 0.6 μm or less with respect to all the carbides is 80 % or more, the HRc exceeds 50 and the good hardenability may be obtained. This is considered to be because fine carbides below 0.6 μm in diameter are rapidly dissolved into austenite phase when

quenching.

But, if the diameter of all the carbides are below 0.6 μm, all the carbides are dissolved into the austenite phase when quenching, so that the austenite grains are remarkably coarsened and the toughness might be deteriorated. For avoiding it, as shown in Fig. 2, more than 50 carbides having a diameter of 1.5 μm or larger should exist in 2500 μm^2 of observation field area of electron microscope.

(ii) Dimensional precision when forming

For improving the dimensional precision when forming, it is necessary that the Δr is made small as described above. But it is not known how small the Δr should be made to obtain an equivalent dimensional precision in gear parts conventionally produced by casting or forging. So, the relationship between Δr and dimensional precision when forming was studied. As a result, it was found that if the Δr was more than -0.15 to less than 0.15, the equivalent dimensional precision in gear parts produced by casting or forging could be provided.

If the Δmax of r-value instead of the Δr is made less than 0.2, the forming can be conducted with a higher dimensional precision.

The high carbon steel sheet under the existing condition of carbides as mentioned in (i) and having a Δr of more than -0.15 to less than 0.15 as mentioned in (ii), can be produced by a method comprising the steps of: hot rolling a steel having chemical

composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, coiling the hot rolled steel sheet at 520 to 600 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at 640 to 690 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or more, and secondarily annealing the cold rolled steel sheet at 620 to 680 °C. Detailed explanation will be made therefor as follows.

(1) Coiling temperature

Since the coiling temperature lower than 520 °C makes pearlite structure very fine, carbides after the primary annealing are considerably fine, so that carbides having a diameter of 1.5 μm or larger cannot be produced after the secondary annealing. In contrast, exceeding 600 °C, coarse pearlite structure is generated, so that carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. Accordingly, the coiling temperature is defined to be 520 to 600 °C.

(2) Primary annealing

If the primary annealing temperature is higher than 690 °C, carbides are too much spheroidized, so that carbides having a diameter of 0.6 μm or less cannot be produced after the secondary annealing. On the other hand, being lower than 640 °C, the spheroidization of carbides is difficult, so that carbides having a diameter of 1.5 μm or larger cannot be produced after the secondary annealing. Accordingly, the primary annealing temperature is defined to be 640 to 690 °C. The annealing time should be 20 hr or longer for uniformly spheroidizing.

(3) Cold reduction rate

In general, the higher the cold reduction rate, the smaller the Δr, and for making Δr more than -0.15 to less than 0.15, the cold reduction rate of at least 50 % is necessary.

(4) Secondary annealing

If the secondary annealing temperature exceeds 680 °C, carbides are greatly coarsened, the grain grows markedly, and the Δr increases. On the other hand, being lower than 620 °C, carbides become fine, and recrystallization and grain growth are not sufficient, so that the workability decreases. Thus, the secondary annealing temperature is defined to be 620 to 680 °C. For the secondary annealing, either a continuous annealing or a box annealing will do.

For producing the high carbon steel sheet under the existing condition of carbides as mentioned in (i) and having a Δmax of r-value of less than 0.2 as mentioned in (ii), the primary annealing temperature T1 and the secondary annealing temperature T2 in the above method should satisfy the following formula (1).

$$1024 - 0.6 \times T1 \leqq T2 \leqq 1202 - 0.80 \times T1 \quad \ldots (1)$$

Detailed explanation will be made therefore as follows.

By making a slab of, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, hot rolling at a finishing temperature of 850 °C and coiling at a coiling temperature of 560 °C, pickling, primarily annealing at 640 to 690 °C for 40 hr , cold rolling at a reduction rate of 60 %, and

secondarily annealing at 610 to 690 °C for 40 hr, steel sheets were produced, and the Δmax of r-value was measured.

As seen in Fig. 3, if the primary annealing temperature T1 is 640 to 690 °C and the secondary annealing temperature T2 is in response to the primary annealing temperature T1 to satisfy the above formula (1), the Δmax of r-value is less than 0.2.

At this time, if the secondary annealing temperature is higher than 680 °C, carbides are coarsened, and carbides having a diameter of 0.6 µm or less cannot be obtained. In contrast, being lower than 620 °C, carbides having a diameter of 1.5 µm or larger cannot be obtained. Therefore, the secondary annealing temperature is defined to be 620 to 680 °C. For the secondary annealing, either a continuous annealing or a box annealing will do.

The Δmax of r-value can be made smaller, if the high carbon steel sheet is produced by such a method comprising the steps of: continuously casting into slab a steel having chemical composition specified by JIS G 4051, JIS G 4401 or JIS G 4802, rough rolling the slab to sheet bar without reheating the slab or after reheating the slab cooled to a certain temperature, finish rolling the sheet bar (rough rolled slab) after reheating the sheet bar to Ar3 transformation point or higher, coiling the finish rolled steel sheet at 500 to 650 °C, descaling the coiled steel sheet, primarily annealing the descaled steel sheet at a temperature T1 of 630 to 700 °C for 20 hr or longer, cold rolling the annealed steel sheet at a reduction rate of 50 % or higher,

and secondarily annealing the cold rolled steel sheet at a temperature T2 of 620 to 680 °C, wherein the temperature T1 and the temperature T2 satisfy the following formula (2).

$$1010 - 0.59 \times T1 \leqq T2 \leqq 1210 - 0.80 \times T1 \quad \ldots (2)$$

At this time, instead of finish rolling the sheet bar after reheating the sheet bar to Ar3 transformation point or higher, by finish rolling the sheet bar during reheating the rolled sheet bar to Ar3 transformation point or higher the similar effect is available. Detailed explanation will be made therefor as follows.

(5) Reheating the sheet bar

By finish rolling the sheet bar after reheating the sheet bar to Ar3 transformation point or higher or during reheating the rolled sheet bar to Ar3 transformation point or higher, crystal grains are uniformed in a thickness direction of steel sheet during rolling, the dispersion of carbides after the secondary annealing is small, and the planar anisotropy of r-value becomes smaller. Accordingly, more excellent hardenability and toughness, and higher dimensional precision when forming are obtained. The reheating time should be at least 3 seconds. As the reheating time is short like this, an induction heating is preferably applied.

(6) Coiling temperature and Primary annealing temperature

If the sheet bar is reheated as above mentioned, the ranges of the coiling temperature and the primary annealing temperature are respectively enlarged to 500 to 650 °C and 630 to 700 °C as compared with the case where the sheet bar is not reheated.

(7) Relationship between primary annealing temperature T1 and secondary annealing temperature T2

By making a slab of, by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %, rough rolling, reheating the sheet bar at 1010 °C for 15 sec by an induction heater, finish rolling at 850 °C, coiling at 560 °C, pickling, primarily annealing at 640 to 700 °C for 40 hr, cold rolling at a reduction rate of 60 %, and secondarily annealing at 610 to 690 °C for 40 hr, steel sheets were produced. Measurements were made on the (222) integrated reflective intensity in the thickness directions (surface, 1/4 thickness and 1/2 thickness) by X-ray diffraction method.

As shown in Table 1, by reheating the sheet bar, the Δmax of (222) intensity being a difference between the maximum value and the minimum value of (222) integrated reflective intensity in the thickness direction becomes small, and therefore the structure is more uniformed in the thickness direction.

As seen in Fig. 4, within the range satisfying the above formula (2), the Δmax of r-value less than 0.15 is obtained. The range satisfying the above formula (2) is wider than that of the formula (1).

Table 1

Reheating of sheet bar (°Cxsec)	Primary annealing (°Cxhr)	Secondary annealing (°Cxhr)	Integrated reflective intensity (222)			
			Surface	1/4 thickness	1/2 thickness	Δmax
1010 x 15	640 x 40	610 x 40	2.81	2.95	2.89	0.14
1010 x 15	640 x 40	650 x 40	2.82	2.88	2.95	0.13
1010 x 15	640 x 40	690 x 40	2.90	2.91	3.02	0.12
1010 x 15	680 x 40	610 x 40	2.37	2.35	2.46	0.11
1010 x 15	680 x 40	650 x 40	2.40	2.36	2.47	0.11
1010 x 15	680 x 40	690 x 40	2.29	2.34	2.39	0.10
-	640 x 40	610 x 40	2.70	3.01	2.90	0.31
-	640 x 40	650 x 40	2.75	2.87	2.99	0.24
-	640 x 40	690 x 40	2.81	2.90	3.05	0.24
-	680 x 40	610 x 40	2.34	2.27	2.50	0.23
-	680 x 40	650 x 40	2.39	2.23	2.51	0.28
-	680 x 40	690 x 40	2.25	2.37	2.45	0.20

For improving sliding property, the high carbon steel sheet of the present invention may be galvanized through an electro-galvanizing process or a hot dip Zn plating process, followed by a phosphating treatment.

To produce the high carbon steel sheet of the present invention, a continuous hot rolling process using a coil box may be applicable. In this case, the sheet bar may be reheated through rough rolling mills, before or after the coil box, or before and after a welding machine.

<u>Example 1</u>

By making a slab containing the chemical composition

specified by S35C of JIS G 4051 (by wt%, C: 0.35 %, Si: 0.20 %, Mn: 0.76 %, P: 0.016 %, S: 0.003 % and Al: 0.026 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 2, and temper rolling at a reduction rate of 1.5 %, the steel sheets A-H of 1.0 mm thickness were produced. Herein, the steel sheet H is a conventional high carbon steel sheet. The existing condition of carbides and the hardenability were investigated by the above mentioned methods. Further, mechanical properties and austenite grain size were measured as follows.

(a) Mechanical properties

JIS No.5 test pieces were sampled from the directions of 0° (L), 45° (S) and 90° (C) with respect to the rolling direction, and subjected to the tensile test at a tension speed of 10 mm/min so as to measure the mechanical properties in each direction. The Δmax of each mechanical property, that is, a difference between the maximum value and the minimum value of each mechanical property, and the Δr were calculated.

(b) Austenite grain size

The cross section in a thickness direction of the quenched test piece for investigating the hardenability was polished, etched, and observed by an optical microscope. The austenite grain size number was measured following JIS G 0551.

The results are shown in Tables 2 and 3.

As to the inventive steel sheets A-C, the existing condition of carbides is within the range of the present invention,

and therefore the HRc after quenching is above 50 and the good hardenability is obtained. The austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, the Δr is more than -0.15 to less than 0.15, that is, the planar anisotropy is very small, and accordingly the forming is carried out with a high dimensional precision. At the same time, the Δmax of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5% or lower, and thus each planar anisotropy is very small.

In contrast, the comparative steel sheets D-H have large Δmax of the mechanical properties and Δr. The steel sheet D has coarse austenite grain size. In the steel sheets E, G, and H, the HRc is less than 50.

Table 2

Steel sheet	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
A	580	650 x 40	70	680 x 40	89	84	Present invention
B	560	640 x 20	60	660 x 40	84	87	Present invention
C	540	660 x 20	65	640 x 40	81	93	Present invention
D	500	640 x 40	60	660 x 40	64	96	Comparative example
E	560	710 x 40	65	660 x 40	103	58	Comparative example
F	540	660 x 20	40	680 x 40	86	84	Comparative example
G	550	640 x 20	60	720 x 40	98	81	Comparative example
H	620	-	50	690 x 40	74	70	Comparative example

Table 3

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δr			
A	395	391	393	4	506	502	507	5	35.7	36.4	35.9	0.7	1.06	0.97	1.04	0.04	52	11.6	Present invention
B	405	404	411	7	504	498	507	9	35.8	36.8	36.2	1.0	1.12	0.98	1.23	0.10	54	11.3	Present invention
C	409	406	414	8	509	505	513	8	35.2	36.4	35.3	1.2	0.98	1.19	1.05	-0.09	56	10.7	Present invention
D	369	362	370	8	499	496	503	9	30.1	29.3	31.0	1.7	1.16	0.92	1.33	0.16	57	8.6	Comparative example
E	370	379	375	9	480	484	481	4	36.9	36.0	36.4	0.9	1.15	0.96	1.47	0.18	44	12.2	Comparative example
F	374	377	385	11	474	480	488	14	35.7	34.6	36.3	1.7	1.25	0.96	1.46	0.20	53	11.2	Comparative example
G	372	376	379	7	496	493	498	5	38.0	37.7	37.7	0.3	1.14	0.94	1.64	0.23	40	12.1	Comparative example
H	317	334	320	17	501	516	510	15	36.5	34.6	35.5	1.9	1.12	0.92	1.35	0.16	49	11.6	Comparative example

Example 2

By making a slab containing the chemical composition specified by S35C of JIS G 4051 (by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 4, and temper rolling at a reduction rate of 1.5 %, the steel sheets 1-19 of 2.5 mm thickness were produced. Herein, the steel sheet 19 is a conventional high carbon steel sheet. The same measurements as in Example 1 were conducted. The Δ max of r-value was calculated in stead of Δr.

The results are shown in Tables 4 and 5.

As to the inventive steel sheets 1-7, the existing condition of carbides is within the range of the present invention, and therefore the HRc after quenching is above 50 and the good hardenability is obtained. The austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, the Δmax of r-value is below 0.2, that is, the planar anisotropy is extremely small, and accordingly the forming is carried out with a high dimensional precision. At the same time, the Δmax of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5% or lower, and thus each planar anisotropy is very small.

In contrast, the comparative steel sheets 8-19 have large Δmax of the mechanical properties. The steel sheets 8, 10, 17 and 18 have coarse austenite grain size. In the steel sheets

9, 11, 15, 16 and 19, the HRc is less than 50.

Table 4

Steel sheet	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
1	580	640 x 40	70	680 x 40	640 – 680	56	85	Present invention
2	530	640 x 20	60	680 x 40	640 - 680	52	87	Present invention
3	595	640 x 40	60	680 x 20	640 - 680	64	81	Present invention
4	580	660 x 40	60	660 x 40	628 - 674	61	83	Present invention
5	580	680 x 20	60	640 x 40	620 - 658	63	82	Present invention
6	580	640 x 40	50	660 x 40	640 - 680	56	85	Present invention
7	580	640 x 40	70	640 x 40	640 - 680	54	86	Present invention
8	510	640 x 20	60	680 x 40	640 - 680	30	92	Comparative example
9	610	640 x 20	60	680 x 20	640 - 680	68	61	Comparative example
10	580	620 x 40	60	680 x 40	–	32	90	Comparative example
11	580	720 x 40	60	680 x 40	–	68	65	Comparative example
12	580	640 x 15	70	680 x 40	640 - 680	54	86	Comparative example
13	580	640 x 40	30	680 x 40	640 - 680	58	84	Comparative example
14	580	660 x 20	60	620 x 40	628 - 674	60	84	Comparative example
15	580	640 x 20	60	700 x 40	640 - 680	66	73	Comparative example
16	580	640 x 40	60	690 x 40	640 - 680	67	70	Comparative example
17	580	690 x 40	60	615 x 40	620 - 650	33	88	Comparative example
18	520	640 x 20	60	640 x 20	640 - 680	45	88	Comparative example
19	620	–	50	690 x 40	–	51	67	Comparative example

Table 5

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
1	398	394	402	8	506	508	513	5	36.2	37.4	37.0	1.2	1.07	0.99	1.00	0.08	54	11.1	Present invention
2	410	407	412	5	513	512	516	4	36.8	38.0	36.8	1.2	1.02	1.01	1.11	0.10	56	10.9	Present invention
3	350	348	351	3	470	474	472	2	36.3	36.8	36.2	0.6	1.01	1.01	1.09	0.08	51	11.6	Present invention
4	395	398	404	9	507	506	509	3	36.6	37.5	37.3	0.9	1.09	0.99	1.01	0.10	52	11.5	Present invention
5	392	397	400	8	502	503	501	2	37.9	38.2	38.0	0.3	0.95	1.13	1.00	0.18	51	11.5	Present invention
6	401	398	407	9	509	509	512	3	37.5	37.9	38.5	1.0	0.94	1.07	1.02	0.13	53	11.3	Present invention
7	404	401	410	9	510	509	512	3	35.3	36.7	36.6	1.4	1.03	1.18	1.01	0.17	55	11.0	Present invention
8	374	367	374	7	507	505	508	3	29.9	28.4	31.3	2.9	1.17	1.01	1.43	0.42	58	8.3	Comparative example
9	371	386	380	15	482	491	485	9	27.1	25.0	26.7	2.1	1.14	0.93	1.31	0.38	40	12.0	Comparative example
10	395	396	399	4	512	512	515	3	27.0	25.4	28.2	2.8	1.27	0.98	1.28	0.30	58	8.9	Comparative example
11	372	384	380	12	484	489	485	5	37.7	36.9	37.3	0.8	1.24	1.00	1.34	0.34	42	12.0	Comparative example
12	390	384	377	13	490	500	498	10	29.0	24.9	29.4	4.5	1.19	0.94	1.29	0.35	56	10.9	Comparative example
13	372	383	390	18	480	486	493	13	35.5	33.7	36.5	2.8	1.02	0.96	1.48	0.52	53	11.3	Comparative example
14	404	401	410	9	510	508	513	5	35.1	37.0	36.7	1.9	1.01	1.28	0.94	0.34	52	11.4	Comparative example
15	385	386	376	10	503	501	506	5	37.5	36.8	36.4	1.1	1.28	1.00	1.31	0.31	45	11.8	Comparative example
16	388	389	378	11	504	501	507	6	37.3	36.5	36.0	1.3	1.18	0.98	1.36	0.38	43	11.9	Comparative example
17	410	408	417	11	513	510	515	5	35.3	38.7	36.5	1.4	1.02	1.26	0.92	0.34	56	9.9	Comparative example
18	412	406	415	9	514	511	519	8	35.1	36.5	36.3	1.4	0.97	1.22	0.88	0.34	57	9.4	Comparative example
19	322	335	322	13	510	519	514	9	36.1	34.1	35.9	2.0	1.12	0.93	1.36	0.43	43	12.0	Comparative example

Example 3

By making a slab containing the chemical composition specified by S65C-CSP of JIS G 4802 (by wt%, C: 0.65 %, Si: 0.19 %, Mn: 0.73 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Table 6, and temper rolling at a reduction rate of 1.5 %, the steel sheets 20-38 of 2.5 mm thickness were produced. Herein, the steel sheet 38 is a conventional high carbon steel sheet. The same measurements as in Example 2 were conducted.

The results are shown in Tables 6 and 7.

As to the inventive steel sheets 20-26, the existing condition of carbides is within the range of the present invention, and therefore the HRc after quenching is above 50 and the good hardenability is obtained. The austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, the Δmax of r-value is below 0.2, that is, the planar anisotropy is extremely small, and accordingly the forming is carried out with a high dimensional precision. At the same time, the Δmax of yield strength and tensile strength is 15 MPa or lower, the Δmax of the total elongation is 1.5% or lower, and thus each planar anisotropy is very small.

In contrast, the comparative steel sheets 27-38 have large Δmax of the mechanical properties. The steel sheets 27, 29 and 36 have coarse austenite grain size. In the steel sheets 28 and 38, the HRc is less than 50.

Table 6

Steel sheet	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
20	560	640 x 40	70	680 x 40	640 - 680	86	86	Present invention
21	530	640 x 20	60	680 x 40	640 - 680	82	88	Present invention
22	595	640 x 40	60	680 x 20	640 - 680	94	82	Present invention
23	560	660 x 40	60	660 x 40	628 - 674	90	83	Present invention
24	560	680 x 20	60	640 x 40	620 - 658	92	83	Present invention
25	560	640 x 40	50	660 x 40	640 - 680	87	85	Present invention
26	560	640 x 40	70	640 x 40	640 - 680	83	86	Present invention
27	510	640 x 20	60	680 x 40	640 - 680	44	93	Comparative example
28	610	640 x 20	60	680 x 20	640 - 680	101	62	Comparative example
29	560	620 x 40	60	680 x 40	-	47	91	Comparative example
30	560	720 x 40	60	680 x 40	-	100	64	Comparative example
31	560	640 x 15	70	680 x 40	640 - 680	83	87	Comparative example
32	560	640 x 40	30	680 x 40	640 - 680	88	85	Comparative example
33	560	660 x 20	60	620 x 40	630 - 674	89	84	Comparative example
34	560	640 x 20	60	700 x 40	640 - 680	98	72	Comparative example
35	560	640 x 40	60	690 x 40	640 - 680	99	70	Comparative example
36	560	690 x 40	60	615 x 40	620 - 650	49	89	Comparative example
37	600	690 x 40	50	650 x 40	620 - 650	96	77	Comparative example
38	620	-	50	690 x 40	-	100	65	Comparative example

Table 7

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
20	412	406	413	7	515	518	523	8	34.2	35.7	35.2	1.5	1.04	0.96	0.97	0.08	63	11.2	Present invention
21	422	419	427	8	524	521	526	5	35.1	36.0	34.6	1.4	0.98	1.00	1.06	0.08	64	11.0	Present invention
22	365	360	363	5	480	483	480	3	34.5	35.0	34.1	0.9	0.97	0.98	1.07	0.10	60	11.7	Present invention
23	409	409	416	7	518	514	519	5	34.7	35.7	34.2	1.5	1.02	0.97	0.93	0.09	61	11.6	Present invention
24	405	410	415	10	511	512	512	1	35.8	36.1	36.2	0.4	0.89	1.11	0.94	0.19	60	11.6	Present invention
25	416	412	423	11	519	517	523	6	35.4	36.0	36.7	1.3	0.92	1.03	0.95	0.14	62	11.4	Present invention
26	417	414	424	10	521	515	524	9	33.4	34.9	34.7	1.5	1.00	1.15	0.98	0.17	63	11.1	Present invention
27	385	380	388	8	518	515	518	3	28.2	24.8	28.2	3.4	1.22	0.96	1.28	0.32	66	8.4	Comparative example
28	385	400	395	15	489	500	493	11	25.7	23.2	25.2	2.5	1.15	0.89	1.22	0.33	48	12.2	Comparative example
29	406	410	413	7	519	523	526	7	25.5	24.0	26.7	2.7	1.21	0.97	1.36	0.39	66	9.0	Comparative example
30	384	397	394	13	492	500	496	8	35.8	34.6	35.6	1.2	1.20	0.90	1.18	0.30	50	12.1	Comparative example
31	405	398	389	16	500	510	511	11	27.1	22.4	27.4	5.0	0.94	1.25	0.97	0.31	64	11.1	Comparative example
32	386	396	406	20	486	497	503	17	33.7	31.9	34.8	2.9	0.81	1.17	0.94	0.36	62	11.4	Comparative example
33	416	412	425	13	521	516	523	7	33.2	35.1	34.8	1.9	1.04	1.32	1.01	0.31	61	11.5	Comparative example
34	402	391	388	14	512	510	515	5	35.7	34.8	34.3	1.4	1.22	0.97	1.34	0.37	53	11.9	Comparative example
35	405	395	394	11	514	511	517	6	35.5	34.8	34.1	1.4	1.17	0.88	1.18	0.30	51	12.0	Comparative example
36	420	417	431	14	523	519	525	6	33.3	34.8	34.5	1.5	1.00	1.26	0.93	0.33	65	10.0	Comparative example
37	375	363	370	12	482	490	485	8	34.3	35.2	34.0	1.2	1.21	0.93	1.24	0.31	56	11.8	Comparative example
38	336	350	331	19	517	528	526	11	34.5	32.4	33.8	2.1	1.10	0.83	1.29	0.44	46	12.4	Comparative example

Example 4

By making a slab containing the chemical composition specified by S35C of JIS G 4051 (by wt%, C: 0.36 %, Si: 0.20 %, Mn: 0.75 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Tables 8 and 9, and temper rolling at a reduction rate of 1.5 %, the steel sheets 39-64 of 2.5 mm thickness were produced. In this example, the reheating of sheet bar was conducted for some steel sheets. Herein, the steel sheet 64 is a conventional high carbon steel sheet. The same measurements as in Example 2 were conducted. The Δmax of (222) intensity as above mentioned was also measured.

The results are shown in Tables 8-12.

As to the inventive steel sheets 39-52, the existing condition of carbides is within the range of the present invention, and therefore the HRc after quenching is above 50 and the good hardenability is obtained. The austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, the Δmax of r-value is below 0.2, that is, the planar anisotropy is extremely small, and accordingly the forming is carried out with a high dimensional precision. At the same time, the Δmax of yield strength and tensile strength is 10 MPa or lower, the Δmax of the total elongation is 1.5% or lower, and thus each planar anisotropy is very small. In particular, the steel sheets 39-45 of which the sheet bar was reheated have small Δmax of (222) intensity in the thickness

direction, and therefore more uniformed structure in the thickness direction.

In contrast, the comparative steel sheets 53-64 have large Δmax of the mechanical properties. The steel sheets 53, 55, 62 and 63 have coarse austenite grain size. In the steel sheets 54, 56, 60, 61 and 64, the HRc is less than 50.

Table 8

Steel sheet	Reheating of sheet bar (°Cxsec)	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
39	1050 x 15	580	640 x 40	70	680 x 40	632 - 680	55	86	Present invention
40	1100 x 3	530	640 x 20	60	680 x 40	632 - 680	52	87	Present invention
41	950 x 3	595	640 x 40	60	680 x 20	632 - 680	64	81	Present invention
42	1050 x 15	580	660 x 40	60	660 x 40	620 - 680	60	84	Present invention
43	1050 x 15	580	680 x 20	60	640 x 40	620 - 666	62	82	Present invention
44	1050 x 15	580	640 x 40	50	660 x 40	632 - 680	56	85	Present invention
45	1050 x 15	580	640 x 40	70	640 x 40	632 - 680	54	86	Present invention
46	-	580	640 x 40	70	680 x 40	632 - 680	56	85	Present invention
47	-	530	640 x 20	60	680 x 40	632 - 680	53	86	Present invention
48	-	595	640 x 40	60	680 x 20	632 - 680	64	81	Present invention
49	-	580	660 x 40	60	660 x 40	620 - 680	61	83	Present invention
50	-	580	680 x 20	60	640 x 40	620 - 666	63	82	Present invention
51	-	580	640 x 40	50	660 x 40	632 - 680	56	85	Present invention

Table 9

Steel sheet	Reheating of sheet bar (°Cxsec)	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
52	-	580	640 x 40	70	640 x 40	632 - 680	55	85	Present invention
53	1050 x 15	510	640 x 20	60	680 x 40	632 - 680	30	92	Comparative example
54	1100 x 3	610	640 x 20	60	680 x 20	632 - 680	67	61	Comparative example
55	950 x 3	580	620 x 40	60	680 x 40	-	32	89	Comparative example
56	1050 x 15	580	720 x 40	60	680 x 40	-	68	65	Comparative example
57	1050 x 15	580	640 x 15	70	680 x 40	632 - 680	55	86	Comparative example
58	1050 x 15	580	640 x 40	30	680 x 40	632 - 680	58	84	Comparative example
59	1050 x 15	580	660 x 20	60	610 x 40	620 - 680	60	84	Comparative example
60	1050 x 15	580	640 x 20	60	700 x 40	632 - 680	66	74	Comparative example
61	1050 x 15	580	640 x 40	60	690 x 40	632 - 680	66	70	Comparative example
62	1050 x 15	580	690 x 40	60	615 x 40	620 - 658	33	88	Comparative example
63	1050 x 15	520	640 x 20	60	640 x 20	632 - 680	45	88	Comparative example
64	1050 x 15	620	-	50	690 x 40	-	33	87	Comparative example

Table 10

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
39	398	394	398	4	506	508	512	6	36.5	37.4	37.0	0.9	1.07	0.99	1.02	0.08	55	11.0	Present invention
40	410	407	410	3	514	512	516	4	36.8	37.7	36.8	0.9	1.04	1.01	1.11	0.10	56	10.9	Present invention
41	351	348	350	3	470	474	473	4	36.4	36.8	36.2	0.6	1.03	1.01	1.09	0.08	51	11.6	Present invention
42	395	398	400	5	508	506	509	3	36.8	37.5	37.3	0.7	1.09	0.99	1.02	0.10	53	11.4	Present invention
43	395	397	400	5	501	503	501	2	37.9	38.2	38.1	0.3	0.95	1.09	1.00	0.14	52	11.4	Present invention
44	401	399	404	5	509	510	512	3	37.7	37.9	38.5	0.8	0.94	1.07	1.04	0.13	53	11.3	Present invention
45	404	401	405	4	511	509	512	3	35.7	36.7	36.6	1.0	1.03	1.15	1.01	0.14	55	11.0	Present invention
46	397	394	402	8	506	508	513	7	36.2	37.4	37.1	1.2	1.14	0.99	1.00	0.15	54	11.1	Present invention
47	409	407	412	5	514	512	516	4	36.8	38.0	36.9	1.2	1.02	1.01	1.14	0.16	55	11.0	Present invention
48	351	348	351	3	470	474	469	5	36.4	36.8	36.2	0.6	1.01	0.98	1.13	0.15	51	11.8	Present invention
49	395	397	404	9	507	505	509	4	36.6	37.5	37.2	0.9	1.13	0.96	1.01	0.17	52	11.5	Present invention
50	392	396	400	8	502	505	501	4	37.2	38.2	38.0	1.0	0.95	1.14	1.00	0.19	51	11.5	Present invention
51	403	398	407	9	509	505	512	3	37.5	37.7	38.5	1.0	0.94	1.12	1.02	0.18	53	11.3	Present invention

Table 11

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
52	405	401	410	9	510	507	512	5	35.3	36.7	36.4	1.4	1.03	1.19	1.00	0.19	54	11.1	Present invention
53	372	364	374	10	507	503	508	5	29.8	28.4	31.3	2.9	1.26	1.02	1.37	0.35	58	8.3	Comparative example
54	371	386	379	15	482	491	484	9	27.1	25.0	26.3	2.1	1.27	0.98	1.27	0.29	41	12.0	Comparative example
55	392	396	399	7	512	509	515	6	27.2	25.4	28.2	2.8	1.33	1.04	1.36	0.32	58	9.0	Comparative example
56	372	385	380	13	484	489	486	5	37.7	36.6	37.3	1.1	1.23	0.95	1.25	0.30	42	12.0	Comparative example
57	390	384	378	12	490	500	497	10	28.8	24.9	29.4	4.5	1.16	0.89	1.20	0.31	55	10.9	Comparative example
58	372	385	390	18	480	487	493	13	35.4	33.7	36.5	2.8	0.88	1.19	0.91	0.31	53	11.3	Comparative example
59	405	401	410	9	510	506	513	7	35.1	37.0	36.6	1.9	1.01	1.27	0.94	0.33	52	11.4	Comparative example
60	383	386	376	10	504	501	506	5	37.5	36.9	36.4	1.1	1.18	0.94	1.29	0.35	45	11.7	Comparative example
61	387	389	378	11	503	501	507	6	37.3	36.6	36.0	1.3	1.16	1.00	1.45	0.45	44	11.9	Comparative example
62	410	404	417	13	513	507	515	8	35.3	36.7	36.1	1.4	0.87	1.17	0.88	0.29	56	9.9	Comparative example
63	411	406	415	9	515	511	515	8	35.1	36.5	36.0	1.4	1.02	1.32	1.00	0.32	57	9.4	Comparative example
64	323	335	322	13	510	519	513	9	36.1	34.1	35.5	2.0	1.10	0.93	1.35	0.40	43	12.0	Comparative example

Table 12

Steel sheet	Integrated reflective intensity (222)				Remark
	Surface	1/4 thickness	1/2 thickness	Δmax	
39	2.80	2.79	2.90	0.11	Present invention
40	2.85	2.92	3.00	0.15	Present invention
41	2.87	2.93	3.00	0.13	Present invention
42	2.72	2.80	2.84	0.12	Present invention
43	2.54	2.60	2.66	0.12	Present invention
44	2.85	2.93	2.99	0.14	Present invention
45	2.88	3.01	2.95	0.13	Present invention
46	2.75	2.90	3.03	0.28	Present invention
47	2.77	3.06	2.98	0.29	Present invention
48	2.79	2.74	3.02	0.28	Present invention
49	2.65	2.77	2.90	0.25	Present invention
50	2.48	2.58	2.75	0.27	Present invention
51	2.80	3.02	2.97	0.22	Present invention
52	2.83	2.80	3.04	0.24	Present invention
53	2.81	2.88	2.96	0.15	Comparative example
54	2.84	2.87	2.98	0.14	Comparative example
55	2.90	3.04	2.99	0.14	Comparative example
56	2.20	2.28	2.32	0.12	Comparative example
57	2.82	2.93	2.91	0.11	Comparative example
58	2.83	2.90	2.98	0.15	Comparative example
59	2.73	2.79	2.86	0.13	Comparative example
60	2.85	2.92	3.00	0.15	Comparative example
61	2.82	2.96	2.93	0.14	Comparative example
62	2.38	2.42	2.53	0.15	Comparative example
63	2.83	2.88	2.96	0.13	Comparative example
64	2.33	2.39	2.48	0.15	Comparative example

Example 5

By making a slab containing the chemical composition specified by S65C-CSP of JIS G 4802 (by wt%, C: 0.65 %, Si: 0.19 %, Mn: 0.73 %, P: 0.011 %, S: 0.002 % and Al: 0.020 %) through a continuous casting process, reheating to 1100 °C, hot rolling, coiling, primarily annealing, cold rolling, secondarily annealing, under the conditions shown in Tables 13 and 14, and temper rolling at a reduction rate of 1.5 %, the steel sheets 65-90 of 2.5 mm thickness were produced. In this example, the reheating of sheet bar was conducted for some steel sheets. Herein, the steel sheet 90 is a conventional high carbon steel sheet. The same measurements as in Example 4 were conducted.

The results are shown in Tables 13-17.

As to the inventive steel sheets 65-78, the existing condition of carbides is within the range of the present invention, and therefore the HRc after quenching is above 50 and the good hardenability is obtained. The austenite grain size of these steel sheets is small, and therefore the excellent toughness is obtained. In addition, the Δmax of r-value is below 0.2, that is, the planar anisotropy is extremely small, and accordingly the forming is carried out with a high dimensional precision. At the same time, the Δmax of yield strength and tensile strength is 15 MPa or lower, the Δmax of the total elongation is 1.5% or lower, and thus each planar anisotropy is very small. In particular, the steel sheets 65-71 of which the sheet bar was reheated have small Δmax of (222) intensity in the thickness direction, and therefore more uniformed structure in the

thickness direction.

In contrast, the comparative steel sheets 79-90 have large Δmax of the mechanical properties. The steel sheets 79, 81 and 88 have coarse austenite grain size. In the steel sheet 80, the HRc is less than 50.

Table 13

Steel sheet	Reheating of sheet bar (°Cxsec)	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
65	1050 x 15	580	640 x 40	70	680 x 40	632 - 680	85	87	Present invention
66	1100 x 3	530	640 x 20	60	680 x 40	632 - 680	82	88	Present invention
67	950 x 3	595	640 x 40	60	680 x 20	632 - 680	94	82	Present invention
68	1050 x 15	560	660 x 40	60	660 x 40	620 - 680	89	84	Present invention
69	1050 x 15	560	680 x 20	60	640 x 40	620 - 666	91	83	Present invention
70	1050 x 15	560	640 x 40	50	660 x 40	632 - 680	87	85	Present invention
71	1050 x 15	560	640 x 40	70	640 x 40	632 - 680	83	86	Present invention
72	-	560	640 x 40	70	680 x 40	632 - 680	86	86	Present invention
73	-	530	640 x 20	60	680 x 40	632 - 680	83	87	Present invention
74	-	595	640 x 40	60	680 x 20	632 - 680	94	82	Present invention
75	-	560	660 x 40	60	660 x 40	620 - 680	90	83	Present invention
76	-	560	680 x 20	60	640 x 40	620 - 666	92	83	Present invention
77	-	560	640 x 40	50	660 x 40	632 - 680	87	85	Present invention

Table 14

Steel sheet	Reheating of sheet bar (°Cxsec)	Coiling temperature (°C)	Primary annealing (°Cxhr)	Cold reduction rate (%)	Secondary annealing (°Cxhr)	Secondary annealing range by the formula (1)	Number of carbides larger than 1.5 μm	Ratio of carbides smaller than 0.6 μm (%)	Remark
78	-	560	640 x 40	70	640 x 40	632 - 680	84	85	Present invention
79	1050 x 15	510	640 x 20	60	680 x 40	632 - 680	44	93	Comparative example
80	1100 x 3	610	640 x 20	60	680 x 20	632 - 680	100	62	Comparative example
81	950 x 3	560	620 x 40	60	680 x 40	-	47	90	Comparative example
82	1050 x 15	560	720 x 40	60	680 x 40	-	100	64	Comparative example
83	1050 x 15	560	640 x 15	70	680 x 40	632 - 680	84	87	Comparative example
84	1050 x 15	560	640 x 40	30	680 x 40	632 - 680	88	85	Comparative example
85	1050 x 15	560	660 x 20	60	610 x 40	620 - 680	89	84	Comparative example
86	1050 x 15	560	640 x 20	60	700 x 40	632 - 680	98	73	Comparative example
87	1050 x 15	560	640 x 40	60	690 x 40	632 - 680	98	70	Comparative example
88	1050 x 15	560	690 x 40	60	615 x 40	620 - 680	49	89	Comparative example
89	1050 x 15	600	690 x 20	50	650 x 40	632 - 680	96	77	Comparative example
90	1050 x 15	610	-	50	690 x 40	-	99	71	Comparative example

Table 15

Steel sheet.	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine Grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
65	412	406	412	6	515	518	521	6	34.7	35.7	35.2	1.0	1.04	0.96	0.98	0.08	64	11.1	Present invention
66	422	419	424	5	523	521	526	5	35.1	36.0	35.1	0.9	0.98	1.02	1.06	0.08	64	11.0	Present invention
67	364	360	363	4	480	483	481	3	34.5	35.0	34.3	0.7	0.97	0.99	1.07	0.10	60	11.7	Present invention
68	409	409	415	6	517	514	519	5	34.7	35.7	34.7	1.0	1.02	0.96	0.93	0.09	62	11.5	Present invention
69	405	410	412	7	511	511	512	1	35.8	36.0	36.2	0.4	0.92	1.06	0.94	0.14	61	11.5	Present invention
70	416	412	421	9	520	517	523	6	35.9	36.0	36.7	0.8	0.89	1.03	0.96	0.14	62	11.4	Present invention
71	417	414	421	7	521	515	521	6	33.9	34.9	34.7	1.0	1.00	1.12	0.98	0.14	63	11.1	Present invention
72	411	406	413	7	515	519	523	8	34.2	35.7	35.3	1.5	1.08	0.93	0.97	0.15	63	11.2	Present invention
73	423	419	427	8	523	521	526	5	35.3	36.0	34.6	1.4	0.94	1.00	1.10	0.16	63	11.1	Present invention
74	365	360	362	5	479	483	480	4	34.6	35.0	34.1	0.9	0.95	0.98	1.12	0.17	60	11.7	Present invention
75	410	409	416	7	517	514	519	5	34.6	35.7	34.2	1.5	1.07	0.97	0.91	0.16	61	11.6	Present invention
76	405	408	415	10	511	512	514	3	35.4	36.1	36.6	1.2	0.92	1.11	0.95	0.19	60	11.6	Present invention
77	417	412	423	11	518	517	523	6	35.4	36.1	36.7	1.3	0.89	1.07	0.95	0.18	62	11.4	Present invention

Table 16

Steel sheet	Mechanical properties before quenching																Hardness after quenching (HRc)	Austetine grain size (size No.)	Remark
	Yield strength (MPa)				Tensile strength (MPa)				Total elongation (%)				r-value						
	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax	L	S	C	Δmax			
78	418	414	424	10	520	515	524	9	33.4	34.9	34.5	1.5	1.00	1.17	0.98	0.19	62	11.2	Present invention
79	385	380	390	10	518	515	520	5	28.0	24.8	28.2	3.4	1.18	0.92	1.25	0.33	66	8.4	Comparative example
80	385	400	394	15	489	500	494	11	25.7	23.2	25.0	2.5	1.12	0.88	1.22	0.34	49	12.2	Comparative example
81	406	410	415	9	519	522	526	7	25.3	24.0	26.7	2.7	1.18	1.01	1.42	0.41	66	9.1	Comparative example
82	384	397	392	13	492	500	497	8	35.8	34.3	35.6	1.5	1.18	0.93	1.32	0.39	50	12.1	Comparative example
83	405	397	389	16	500	509	511	11	27.0	22.4	27.4	5.0	1.24	0.90	1.27	0.37	63	11.1	Comparative example
84	386	398	406	20	486	496	503	17	33.4	31.9	34.8	2.9	0.81	1.16	0.93	0.35	62	11.4	Comparative example
85	418	412	425	13	521	516	524	8	33.2	35.1	34.5	1.9	1.02	1.23	0.86	0.37	61	11.5	Comparative example
86	402	393	388	14	512	509	515	6	35.7	34.9	34.3	1.4	1.24	0.95	1.25	0.30	53	11.8	Comparative example
87	406	395	394	12	514	510	517	7	35.5	34.7	34.1	1.4	1.11	0.86	1.19	0.33	52	12.0	Comparative example
88	421	417	431	14	523	518	525	7	33.3	34.8	34.3	1.5	1.00	1.26	0.92	0.34	65	10.0	Comparative example
89	375	363	369	12	482	490	486	8	34.3	35.4	34.0	1.4	1.17	0.99	1.40	0.41	56	11.8	Comparative example
90	338	350	331	19	517	528	524	11	34.5	32.4	33.6	2.1	1.13	0.83	1.29	0.42	54	11.9	Comparative example

Table 17

Steel sheet	Integrated reflective intensity (222)				Remark
	Surface	1/4 thickness	1/2 thickness	Δ max	
65	2.87	2.82	2.97	0.15	Present invention
66	2.83	2.86	2.94	0.11	Present invention
67	2.85	2.90	2.97	0.12	Present invention
68	2.75	2.81	2.86	0.11	Present invention
69	2.58	2.64	2.71	0.13	Present invention
70	2.84	2.91	2.96	0.12	Present invention
71	2.85	2.99	2.95	0.14	Present invention
72	2.73	2.85	3.02	0.29	Present invention
73	2.76	3.03	2.97	0.27	Present invention
74	2.78	2.92	3.04	0.26	Present invention
75	2.69	2.82	2.96	0.27	Present invention
76	2.50	2.64	2.75	0.25	Present invention
77	2.81	3.03	2.99	0.22	Present invention
78	2.79	2.87	3.03	0.24	Present invention
79	2.83	2.87	2.96	0.13	Comparative example
80	2.84	2.88	2.99	0.15	Comparative example
81	2.92	3.03	2.95	0.11	Comparative example
82	2.22	2.26	2.34	0.12	Comparative example
83	2.85	2.97	2.92	0.12	Comparative example
84	2.88	2.94	3.02	0.14	Comparative example
85	2.73	2.75	2.87	0.14	Comparative example
86	2.84	2.87	2.99	0.15	Comparative example
87	2.86	3.01	2.92	0.15	Comparative example
88	2.40	2.42	2.54	0.14	Comparative example
89	2.89	2.98	3.04	0.15	Comparative example
90	2.37	2.40	2.50	0.13	Comparative example